

Dimuon production in p-nucleus and nucleus-nucleus collisions: the NA60 experiment

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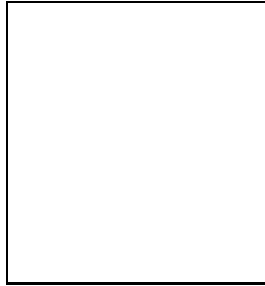
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The measurements of dilepton production in heavy-ion collisions performed at the CERN SPS provided some of the most interesting observations done so far in the search for quark gluon plasma formation. However, certain aspects in the interpretation of these measurements remain unclear and require further studies. Thanks to a radiation tolerant silicon pixel telescope, NA60 has measured, in 2003, dimuon production in nuclear collisions with unprecedented accuracy. The physics topics under study include the J/ψ suppression pattern, the excess of the intermediate mass dimuons and of low mass dileptons. In this paper, after briefly summarizing the NA60 physics motivations and the detector concept, we present some preliminary results from Indium-Indium collisions at 158 GeV.

Lattice QCD predicts that, above a critical temperature or energy density, strongly interacting matter undergoes a phase transition from hadronic matter to a new state named Quark Gluon Plasma (QGP). In this new state quarks and gluons are no longer confined into hadrons and chiral symmetry is restored. Since 1986, at the CERN SPS, several experiments searched

for this phase transition in heavy ion collisions. The results of this research program provided compelling evidence for the production of a new state of matter in high-energy Pb-Pb collisions. However, further work is needed to clarify some aspects of these “anomalous” observations.

The dimuon mass spectrum between the ϕ and the J/ψ resonances is dominated by Drell-Yan and simultaneous semi-leptonic decays of D mesons. The superposition of these two sources describes the measurements done in p-A collisions, while in A-A collisions the dimuon mass spectrum shows an excess which grows with the number of nucleons participating in the interaction. Two interpretations of this excess have been considered: it can be due to an unexpected enhancement of charm production or to thermal dimuons emitted from the QGP phase. This question will be answered by extrapolating the muon tracks back to the target: thermal dimuons are emitted directly from the interaction point, while muons from charmed mesons come from vertices displaced with respect to the primary one. Thanks to the vertex pixel telescope, NA60 can measure the transverse coordinate of the tracks at the target, with 50 μm accuracy.

The CERES experiment at the CERN SPS measured the dielectron invariant mass spectrum in Pb-Au collisions at 158 GeV. A comparison with the expected sources (mainly light meson decays, which describe the proton data) shows an excess in the mass range 0.2–0.7 GeV/ c^2 . This observation has been interpreted as an indication of changes in the mass and decay width of the ρ meson, maybe due to partial restoration of the chiral symmetry. However, this result suffers from lack of statistics and a poor signal-to-background ratio. To clarify these issues NA60 will increase the statistics and improve the mass resolution and signal to background ratio. The excess will also be studied as a function of the transverse momentum and the collision centrality.

The J/ψ suppression, as a signature of the formation of a deconfined state, has been studied by NA38 and NA50. In Pb-Pb collisions the J/ψ production pattern, as a function of the collision centrality, shows that above a certain centrality threshold the J/ψ yield is considerably lower than expected from the “nuclear absorption” curve, derived from proton-nucleus and light ions data. One of the current interpretations of this result is that the dense and hot medium formed in the collisions dissolves the χ_c resonance, leading to the disappearance of the fraction ($\sim 30\%$) of J/ψ mesons that would otherwise originate from χ_c decays. Several questions remain open. What is the physical variable driving the J/ψ suppression? Is it the number of participant nucleons? Or the local energy density? Or the average length of nuclear matter, L , traversed by the charmonium state? The results from the In-In data will allow NA60 to answer these questions. Furthermore, in 2004 NA60 will study the A dependence of χ_c production, with a proton beam at 400 GeV, in order to understand the level of this feed-down source.

In terms of detector layout, the NA60 experiment complements the Muon Spectrometer and Zero Degree Calorimeter inherited from the NA50 experiment with a completely new target region, where silicon micro-strip and pixel detectors, integrated in a 2.5 T dipole magnet, allow us to track the charged particles produced in the collisions and accurately determine primary and secondary vertices. By matching the muons measured in the muon spectrometer to tracks in the silicon vertex telescope, simultaneously using information on coordinates and momentum, we are able to overcome the uncertainties introduced by multiple scattering and energy loss fluctuations, induced by the crossing of the hadron absorber. Besides the obvious improvement in dimuon mass resolution, we are also able to accurately determine the origin of the muons, and separate prompt dimuons (Drell-Yan, thermal) from the muon pairs due to decays of D mesons.

The NA60 detector concept became feasible thanks to the recent availability of radiation tolerant silicon pixel read-out chips, developed in view of the LHC experiments. In the 5-week long Indium run of October-November 2003, in particular, we could reconstruct the charged particles trajectories thanks to 11 tracking points provided by 16 modules covering the muon spectrometer’s angular acceptance ($3 < \eta_{\text{lab}} < 4$). The basic units of these detector planes are the ALICE1LHCb pixel chips, of 32×256 cells of $425 \times 50 \mu\text{m}^2$ area. The kind of accuracy reached with these detectors can be appreciated by looking at the Z-vertex distribution (left

panel of Fig. 1) of the interaction vertices, where we can easily distinguish, with $\sim 200 \mu\text{m}$ resolution, the seven Indium targets in-between the two target box windows (the target was in vacuum). We can also see the sensor of a beam tracker module, 10 cm up-stream of the target centre.

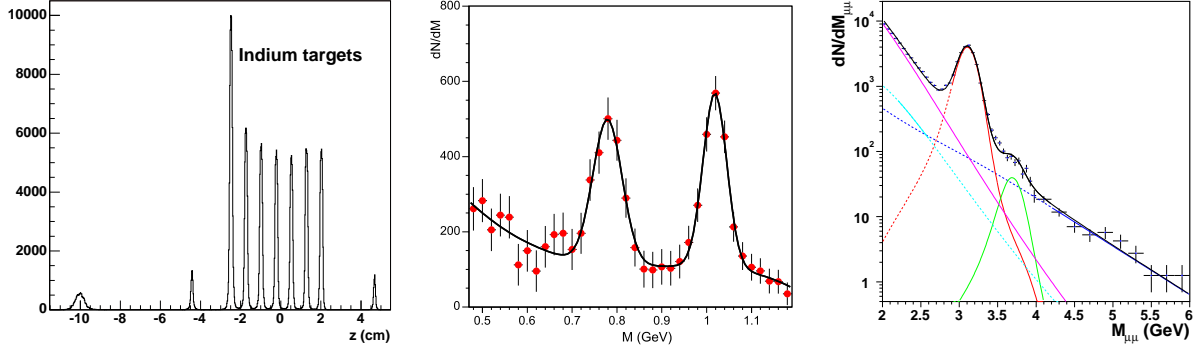


Figure 1: Distributions measured in Indium-Indium collisions: the z -coordinate of the reconstructed vertices (left), the low mass dimuon signal after track matching (centre), and the high mass spectrum before track matching and background subtraction (right).

Out of the more than 200 million dimuon triggers collected, we expect to retain around one million low mass signal dimuons, after track matching and background subtraction. The second panel of Fig. 1 shows the extracted signal dimuon spectrum in the region of the ω and ϕ resonances, on the basis of around 1% of the collected statistics. It already shows a mass resolution around 20–25 MeV, in spite of the fact that the reconstruction was done with a preliminary version of the offline software. The combinatorial background resulting from π and K decays was estimated through a mixed-event technique, based on the like-sign muon pairs. The analysis of low mass dimuon production can be done down to very low dimuon transverse momentum and as a function of the collision centrality.

The muon track matching is not so crucial for the analysis of the J/ψ meson, clearly visible over the underlying continuum even with a mass resolution of 100 MeV, as can be seen in the right panel of Fig. 1. Also this figure is made with only a fraction (around 50%) of the collected data and having applied a severe event selection procedure, to eliminate pile-up and events with interactions out of the targets.

The dimuon mass region above 2 GeV contains the J/ψ and ψ' resonances sitting on a continuum composed of Drell-Yan dimuons and of muon pairs from decays of D mesons, besides the combinatorial background from π and K decays, which we determine from the measured like-sign muon pairs. In order to extract the ratio between the J/ψ and the Drell-Yan production cross-sections, integrated over all collision centralities where $E_{\text{ZDC}} < 15 \text{ TeV}$, we fit the opposite-sign dimuon mass distribution to a superposition of the contributions just mentioned. The corresponding mass distributions are evaluated through a detailed Monte Carlo simulation, using Pythia for the event generation and GEANT for the reproduction of the detector effects. The events are then reconstructed as the real data. Besides the simulated invariant mass spectra, these calculations also provide the J/ψ and Drell-Yan acceptances, $A_\psi = 12.4\%$ and $A_{DY(2.9-4.5)} = 13.4\%$, in our phase space window: $0 < y_{\text{cms}} < 1$ and $|\cos(\theta_{\text{CS}})| < 0.5$. The fit proceeds in three consecutive steps: first we determine the Drell-Yan yield from the mass region above 4.2 GeV; then we determine the charm normalization from the mass window $2.2 < M < 2.5 \text{ GeV}$ (having fixed the Drell-Yan from the previous step); finally we extract the J/ψ and ψ' yields, and the exact position and width of the J/ψ peak, from the mass region $2.9 < M < 4.2 \text{ GeV}$. We should note that the ratio ψ/DY is completely insensitive to the specific level of open charm decays we use and it would change by less than 3% if the background would

be 10 % higher.

In order to compare with previous results, published by the NA38 and NA50 experiments, obtained in p-nucleus, S-U, and Pb-Pb collisions, we refer our Indium-Indium result to the Drell-Yan production cross-section integrated in the mass domain between 2.9 and 4.5 GeV. Our analysis gives a ψ/DY ratio of 19.5 ± 1.6 . A more detailed work is on-going but we do not expect that this preliminary value will change by more than 10 %.

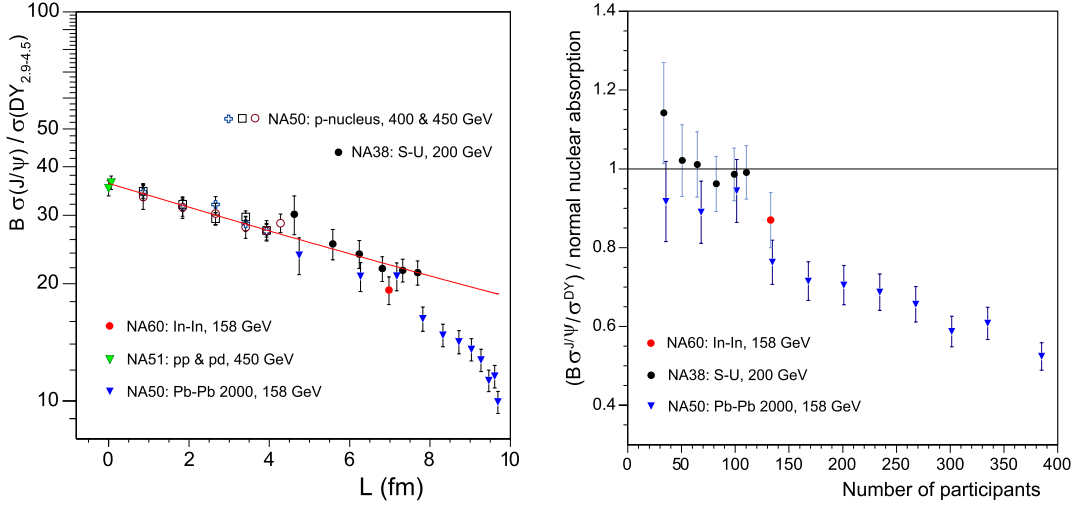


Figure 2: J/ψ suppression pattern versus L (left) and N_{part} (right), including the Indium-Indium measurement.

Figure 2 shows how the Indium-Indium point compares to the previously established J/ψ suppression pattern, both as a function of L , the thickness of nuclear matter traversed by the charmonium state, on the left panel, and as a function of the number of nucleons involved in the collision, N_{part} , on the right panel. In the latter figure the data points are plotted with respect to the normal nuclear absorption curve, determined from the p-A measurements, which can be seen in the left panel (continuous line). Our Indium-Indium measurement, when referred to the absorption curve, gives the value 0.87 ± 0.07 . While in the L representation our In-In point sits (at 7.0 fm) to the left of the most central S-U value, in the N_{part} plot we see the contrary. Once all the collected Indium data will be fully analyzed, we should be able to probe the J/ψ suppression pattern as a function of centrality, in the ranges 5.5–7.8 fm in L and 50–200 in N_{part} . By comparing the In-In and Pb-Pb patterns as a function of different centrality variables, we should understand which is the variable and, therefore, the physics mechanism, driving the J/ψ suppression. In particular, we should be able to distinguish between the thermal (QGP) and geometrical (percolation) phase transitions, both resulting in the suppression of J/ψ production but as a function of different variables and with different thresholds in collision centrality. It is very important that the theorists provide now, *before* the centrality dependence of our Indium data is presented, the corresponding predictions of their models.

In summary, we have presented preliminary results from the Indium data collected by NA60 at the end of 2003, revealing a very substantial improvement in the quality of the measurements with respect to previous experiments, with important impacts in our understanding of the low mass dilepton production and of the J/ψ suppression pattern. Integrating the Indium data over collision centralities up to $E_{\text{ZDC}} = 15$ TeV, we obtain a preliminary value for the ratio ψ/DY , 19.5 ± 1.6 , which we compared with previous measurements. More detailed results, also on open charm production, will be available soon. In 2004, high statistics proton-nucleus data will be taken, providing an accurate reference baseline to understand the heavy-ion results.